sPHENIX tracking simulations

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sPHENIX Cost & Schedule Review
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The tracking options

The tracking options being considered are:

Reused PHENIX pixels OR MAPS based pixels	+	Silicon strip outer tracker OR TPC outer tracker

The goal of the tracking simulations is to characterize the performance of all of the possible combinations

Outline

- Simulations overview
- Results so far
- Future plans

Overview of silicon tracking simulations

So far the sPHENIX silicon tracking simulations have been done with:

Cylinder cell geometry in G4:

- Make a cylinder, subdivide it into cells (pixel or strip)
- Each cell:
  - Sensor material
  - Cu layer to represent average electronics, support, cooling material

Hit finding, clusterizing, tracking, ghost rejection:

- Hough Transform to find tracks
- Kalman Filter to extract track parameters
- Evaluation objects!
- Extensive tuning done for central HIJING events
- Works well

BUT: All of the tracking simulations done up to the pCDR assume an essentially perfect detector

- although estimated yields do contain reasonable(?) reality factors

TPC tracking simulations

So far the sPHENIX TPC gas simulations have been done with:

Cylinder cell geometry in G4:

- Make a cylinder of gas,
- subdivide it radially into cells,
  - 45 cells radially, 1 degree in r-Φ
- Drift each voxel to the readout plane
- Diffuse it transversely
- Make a readout plane configuration
- Impose readout parameters to get realistic coverage of pads

Still early days:

- Good estimates of momentum resolution, Upsilon mass resolution
- Lots of work still to characterize tracking performance in AuAu
- Need realistic simulation of space charge effects
  - Can we get 100 MeV Upsilon resolution at 50 kHz Au+Au rates?

Results to date - silicon tracker configuration

Consider the 5 layer silicon tracker configured for the FPHX chip +

- The reused PHENIX pixels
- OR a 3 layer MAPS pixel detector (we use r = 2.4, 4.0, 6.0 cm here)

Station	Layer	radius (cm)	pitch (μm)	sensor length (cm)	depth (μm)	total thickness X_0%	area (m^2)
Pixel	1	2.4	50	0.425	200	1.3	0.034
Pixel	2	4.4	50	0.425	200	1.3	0.059
S0a	3	7.5	58	9.6	240	1.0	0.18
S0b	4	8.5	58	9.6	240	1.0	0.18
S1a	5	31.0	58	9.6	240	0.6	1.4
S1b	6	34.0	58	9.6	240	0.6	1.4
S2	7	64.0	60	9.6	320	1.0	6.5

OR replace pixels with

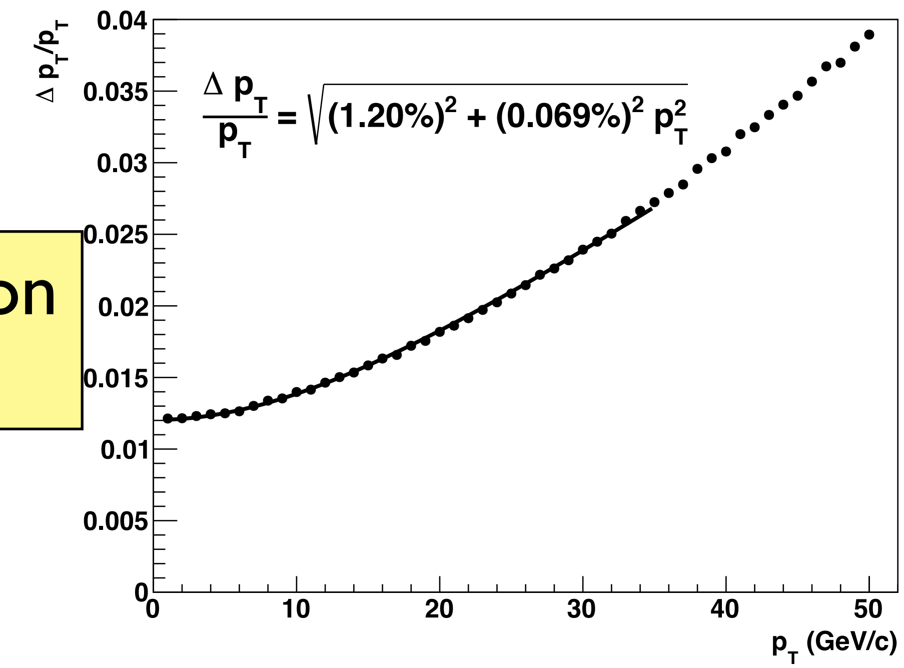
Layer	radius (cm)	pitch (μm)	sensor length (μm)	depth (μm)	total thickness X_0%	length (cm)	area (m^2)
1	2.4	28	28	50	0.3	27	0.041
2	~4	28	28	50	0.3	27	~0.068
3	~6-15	28	28	50	0.3	~27-39	~0.102-0.368

Results to date - silicon tracker - single particle resolution

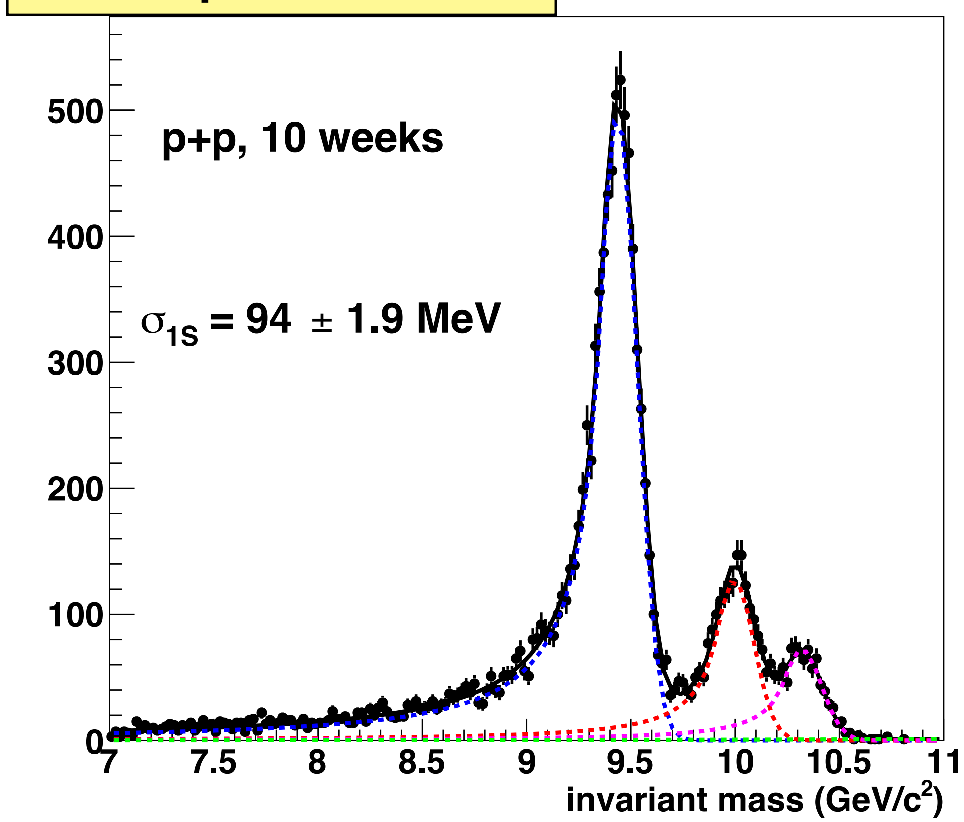
Assume (for the moment) 100% live pixels

- Single pion p_T resolution
- Upsilon mass resolution

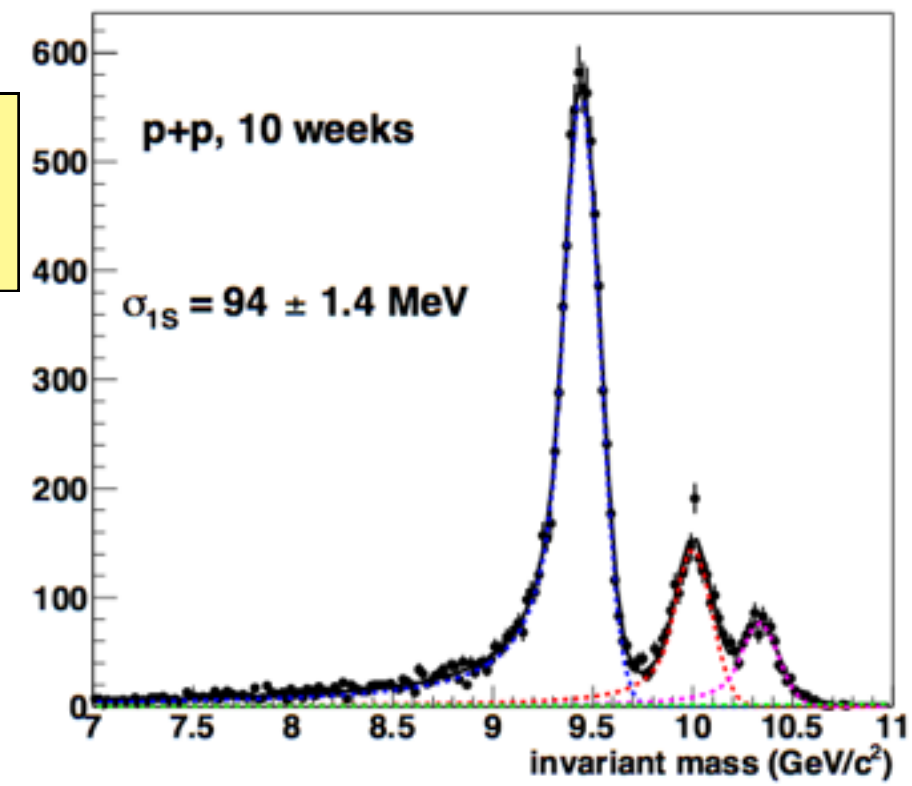
single pion p_T resolution (either pixel option)



Reused PHENIX pixels



3 layer MAPS Pixels



Effect of dead pixels on Upsilon measurement

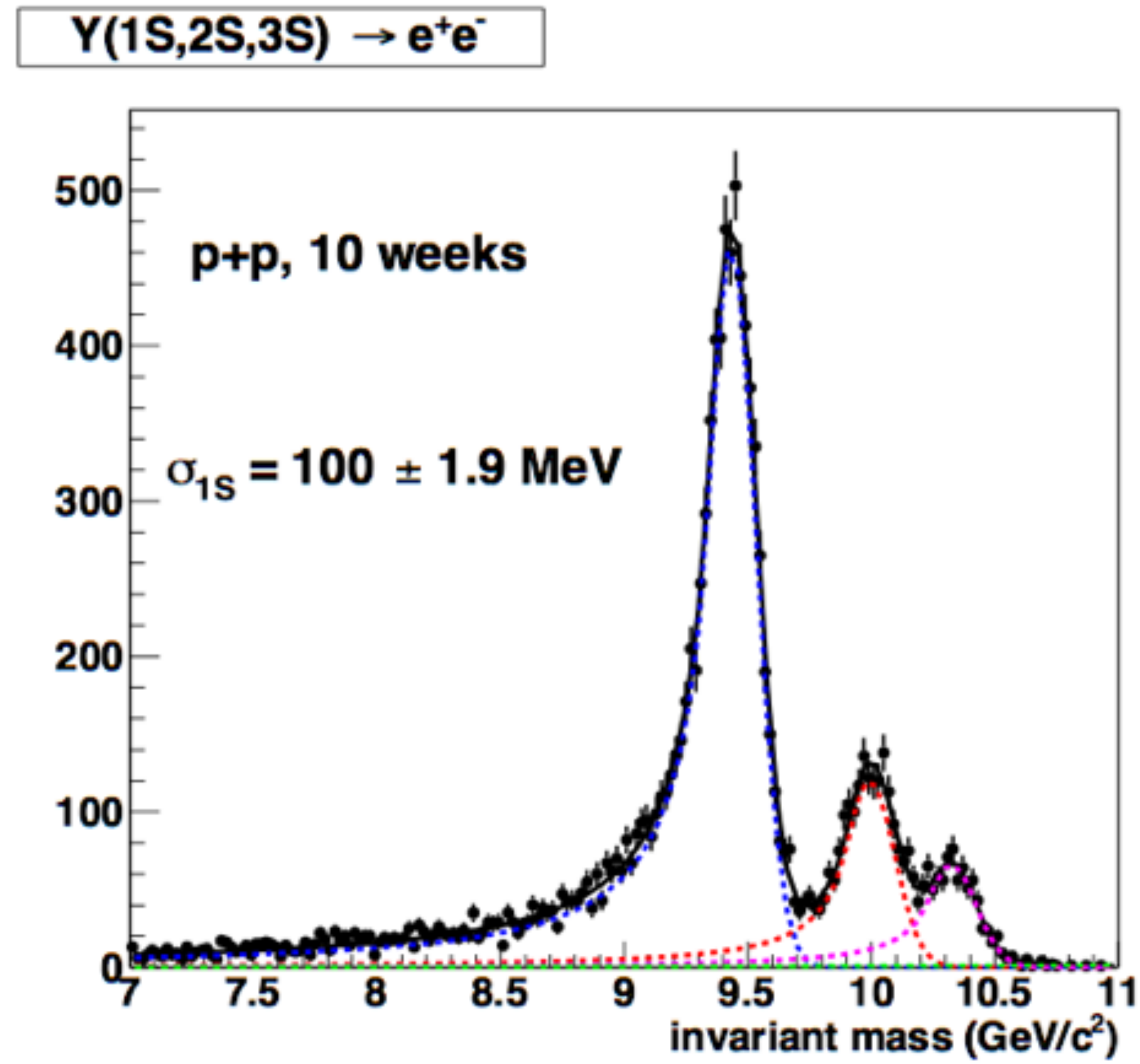
Do the dead pixels in the reuse option cause problems for the Upsilon measurement?

Make layer 1 92.5% live
Make pixel layer 2 72.5% live

Require hits in only 6 of the 7 layers

- Acceptance increases slightly
- Some loss of resolution
  - likely recover it with tracker setup

Not so bad!



BUT: Requiring only 6 layers results in large rates of fake tracks. Probably can be resolved using calorimeter match for Upsilon decay electrons

- Potentially a much more serious problem for other physics

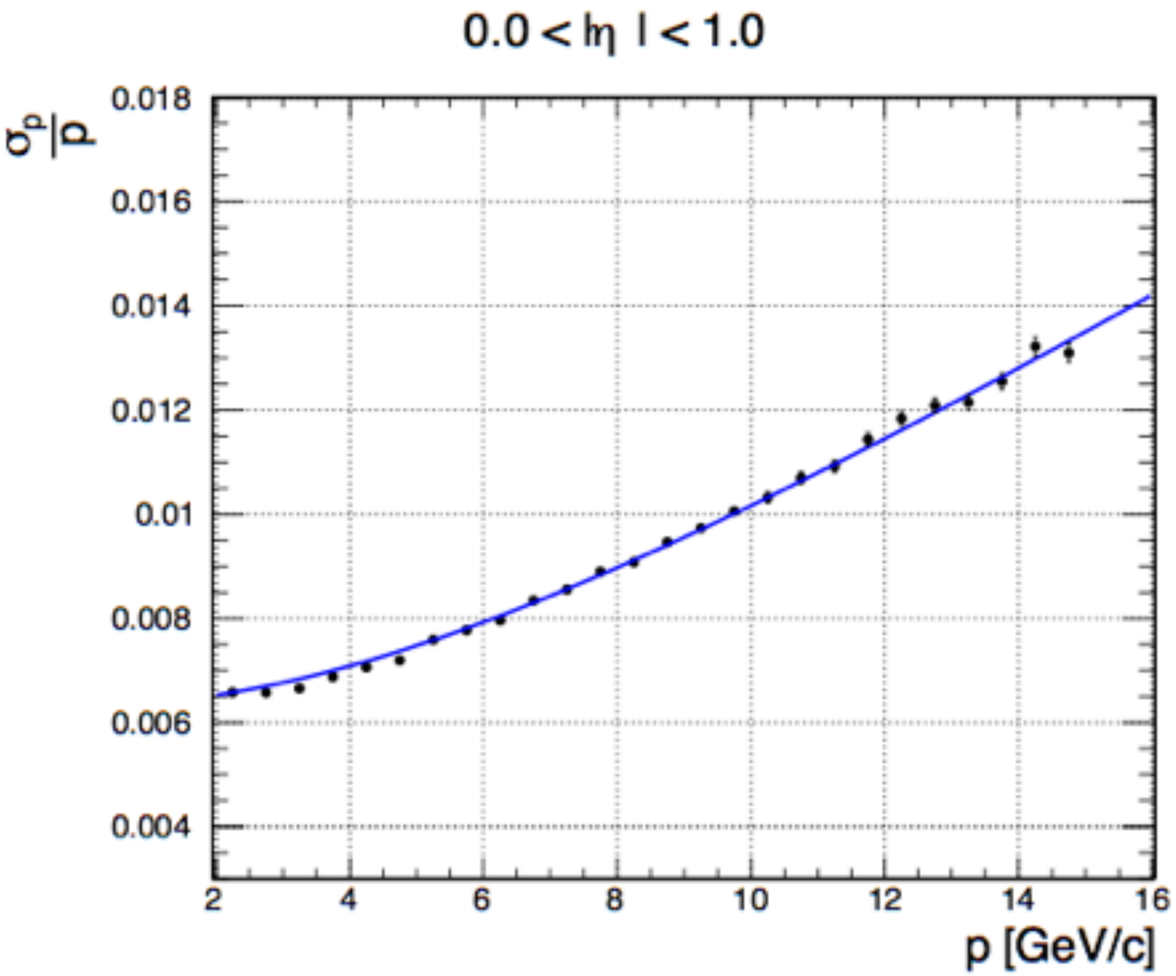
Results to date - TPC - single particle resolution

Configuration used for simulations so far:

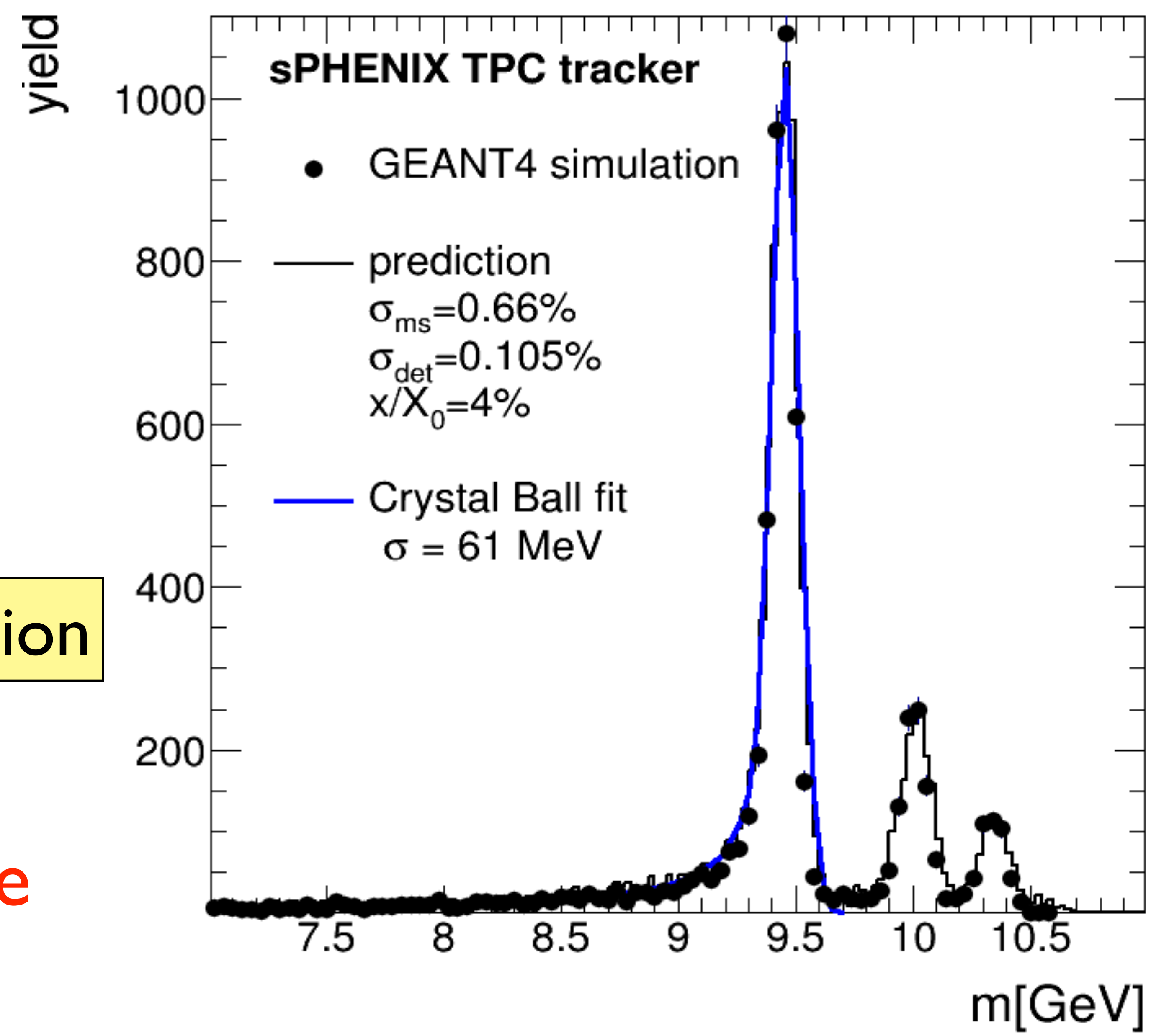
layer	radius (cm)	Thickness % χ_0	$\frac{\Delta L}{L}$	c_{ms} (mrad)	σ_{ms} (mrad)
VTX 1	2.7	1.3	0.95	1.8	1.7
VTX 2	4.6	1.3	0.92	1.8	1.7
air	15	0.1	0.73	0.03	0.02
Field cage	30	1.0	0.55	1.12	0.5

Assume (for now) pixels are 100% live.

Results to date - TPC - single particle resolution



Single pion p_T resolution



Single Upsilon mass resolution

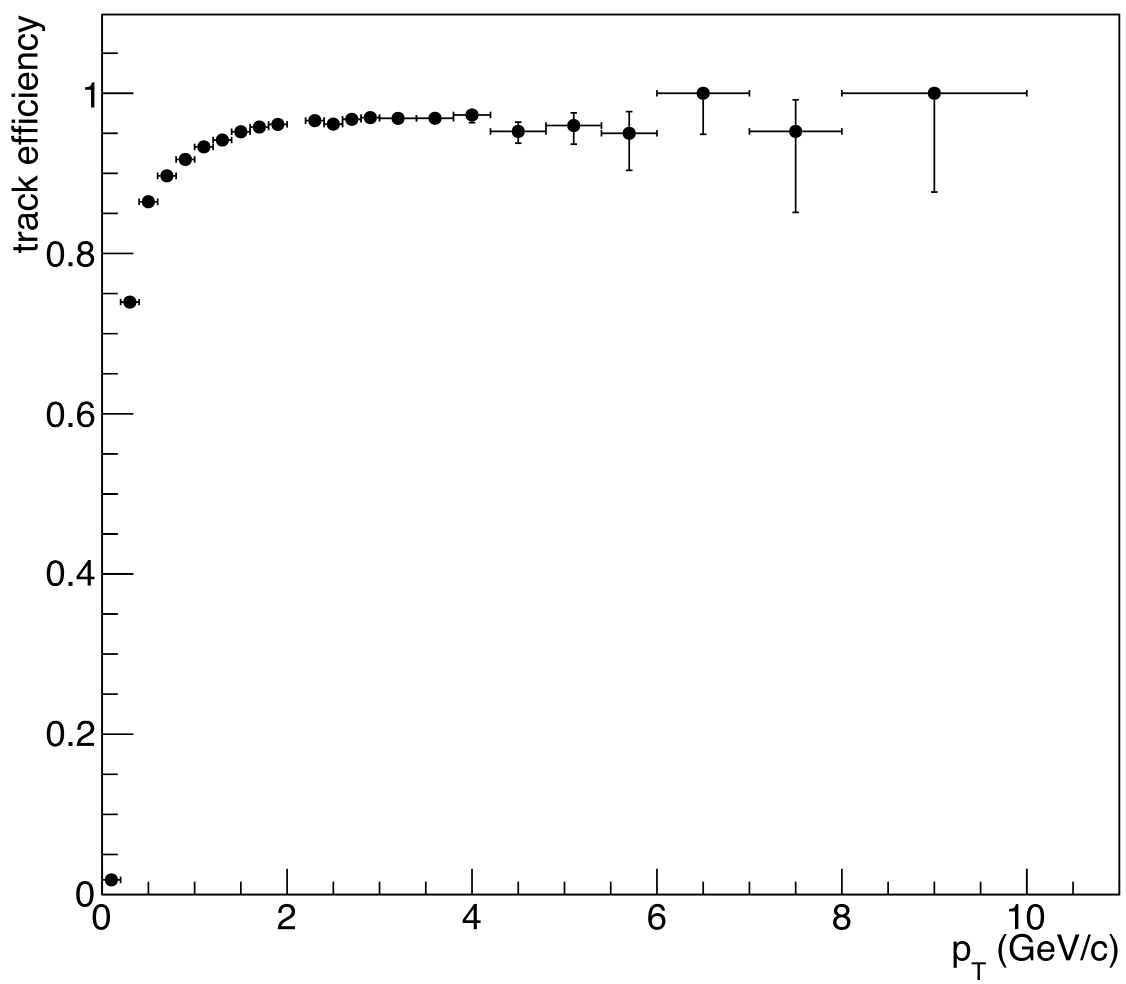
But keep in mind that this simulation does not yet include the effects of space charge!

Results to date - silicon tracker - AuAu central

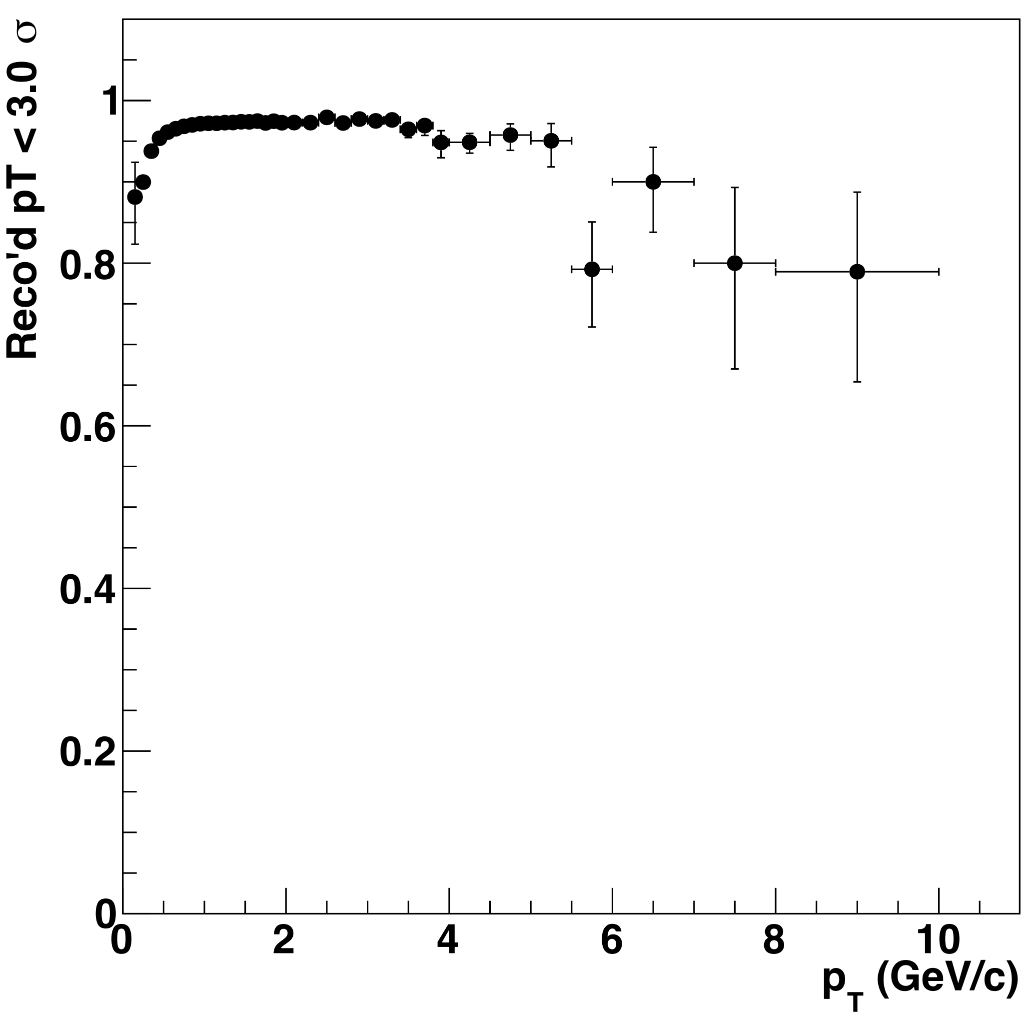
Performance of the silicon strip tracker + **reused pixels** (assume pixels 100% efficient for now) in 5000 central AuAu HIJING events

- Look at track efficiency and track purity

Reconstruction efficiency
all truth tracks reconstructed within
3 σ of truth p_T



Track purity
all reconstructed tracks within
3 σ of truth p_T

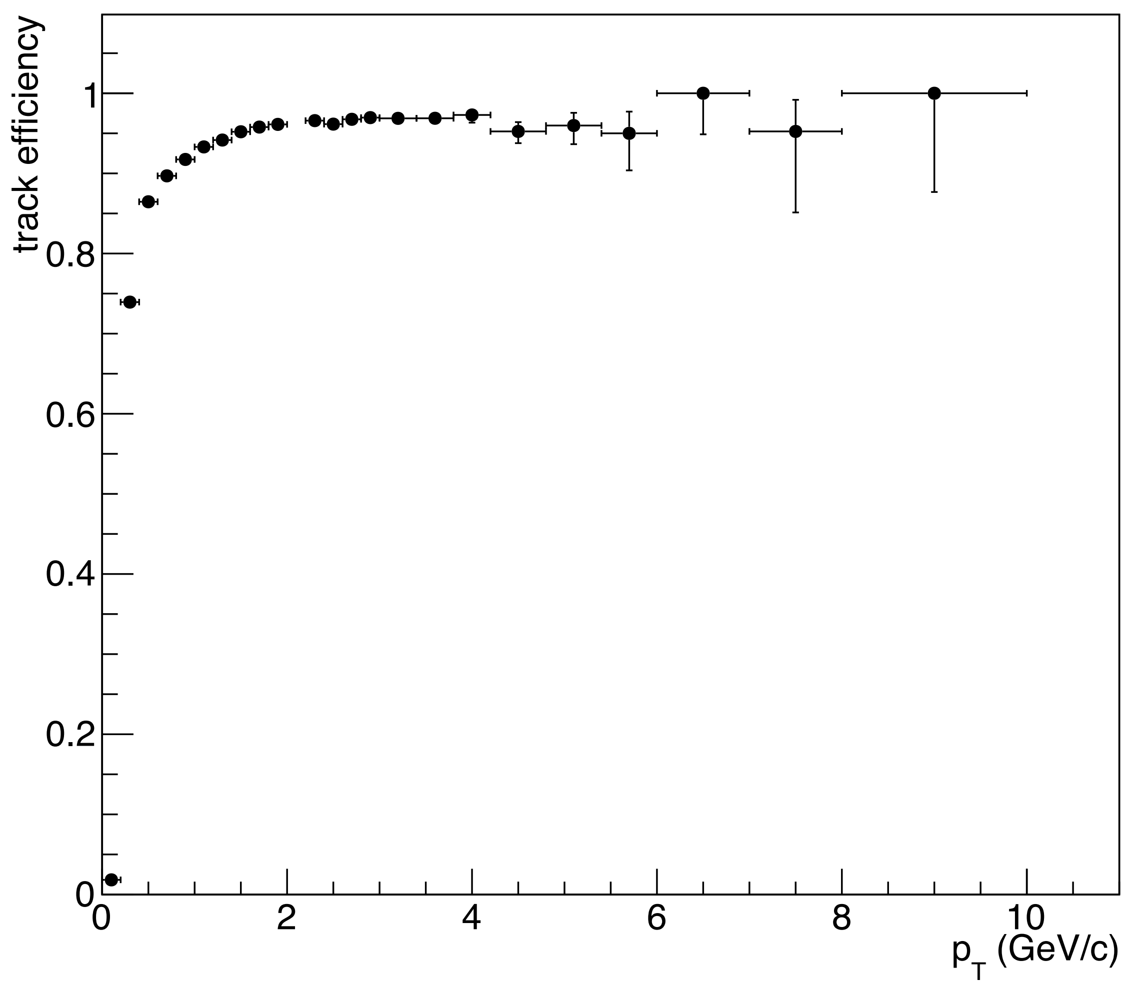


Results to date - silicon tracker - AuAu central

Performance of the silicon strip tracker + **MAPS pixels** in 2000 central AuAu HIJING events

- Look at track efficiency and track purity

Reconstruction efficiency
all truth tracks reconstructed within
3 σ of truth p_T



Track purity
all reconstructed tracks within
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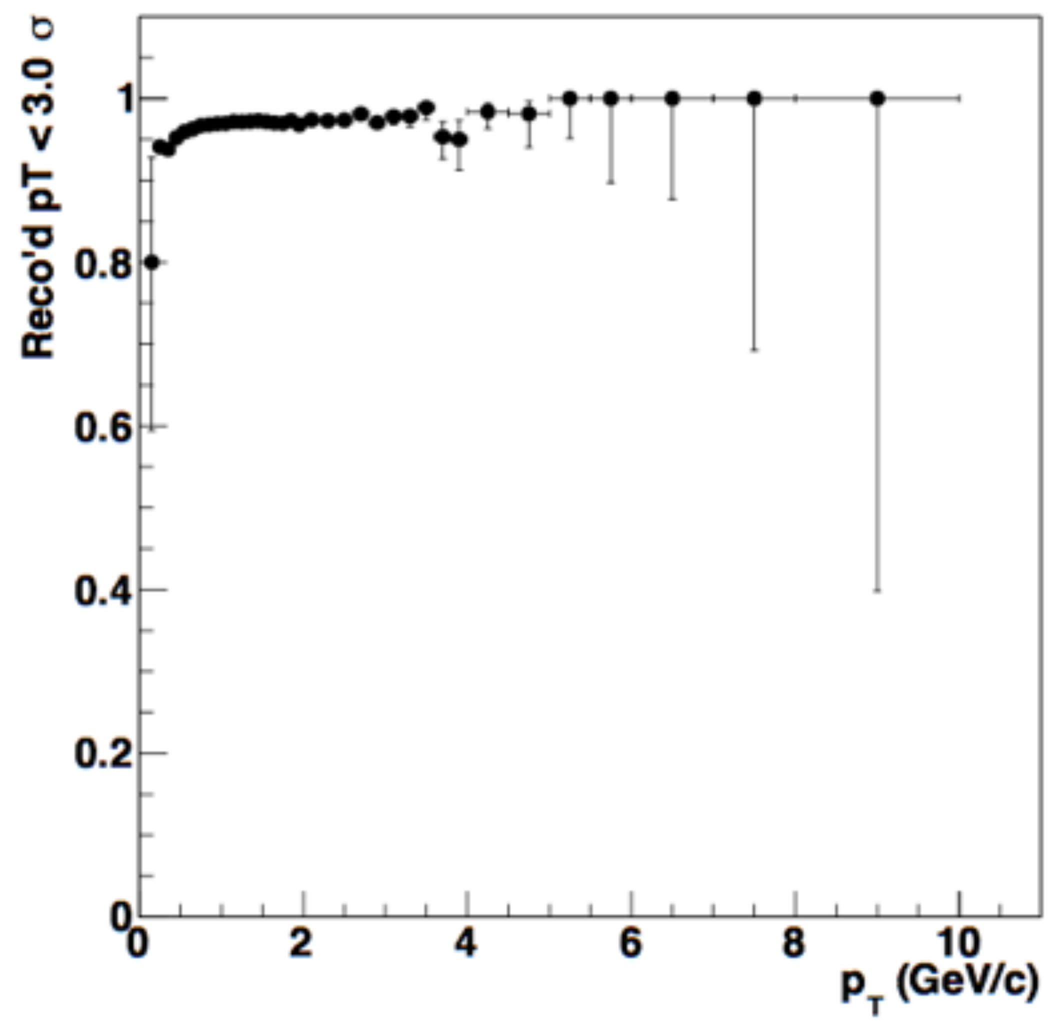
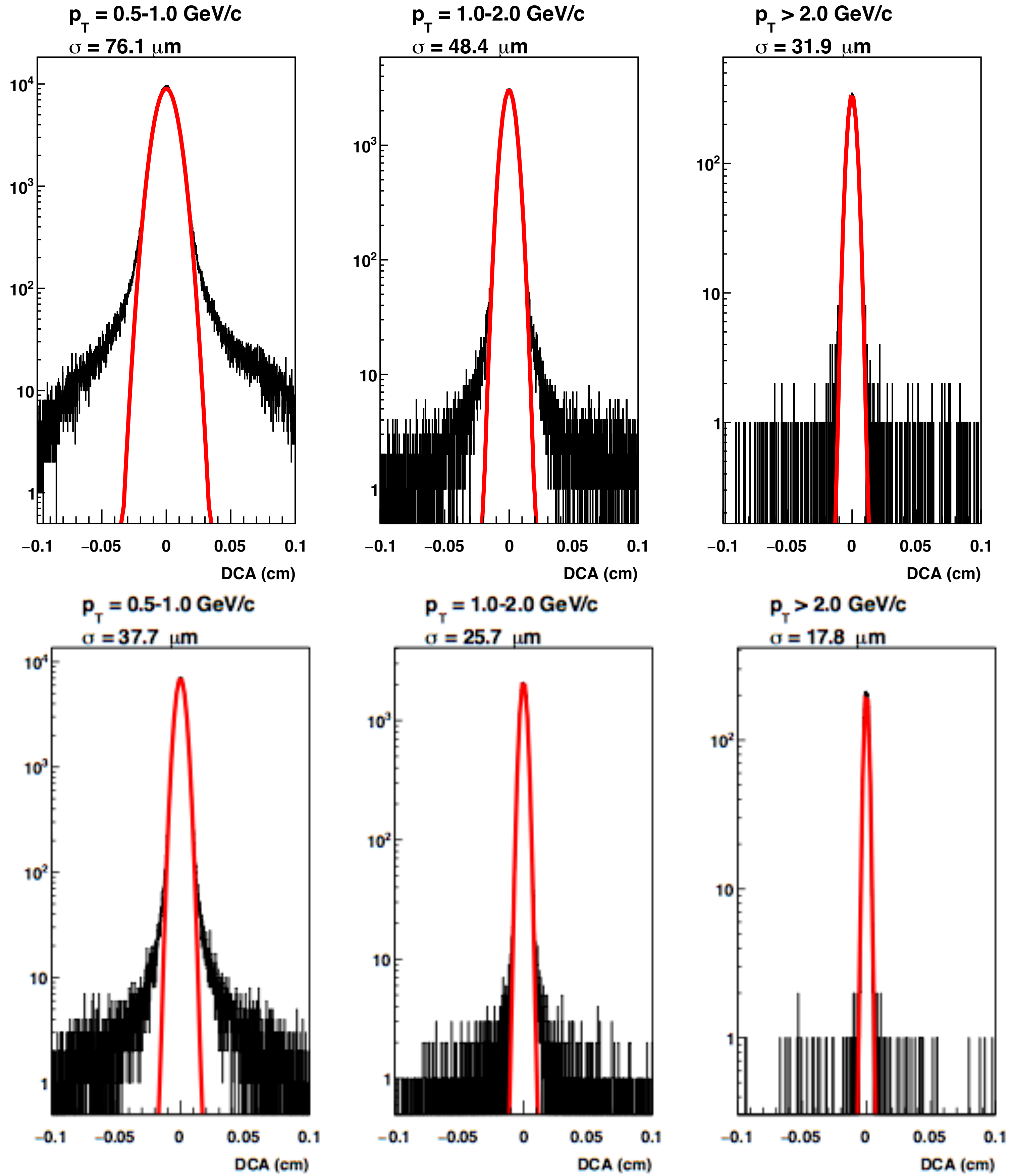


Results to date - silicon tracker - AuAu central

2000 central HIJING AuAu events:



Silicon strip + reused pixels

- Meets our spec of < 100 μm
- 46 μm for p_T = 1-2 GeV/c

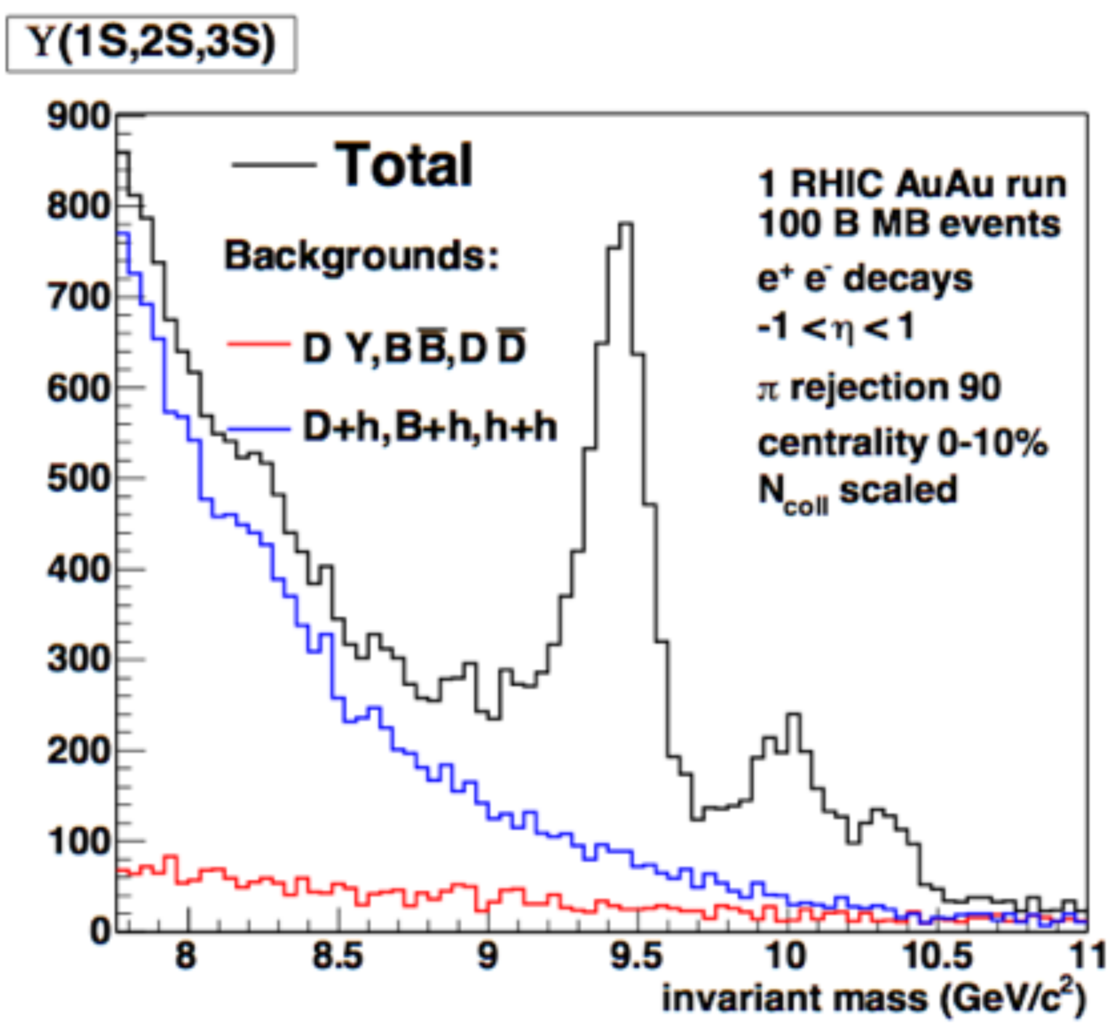
Silicon strip + 3 layer MAPS

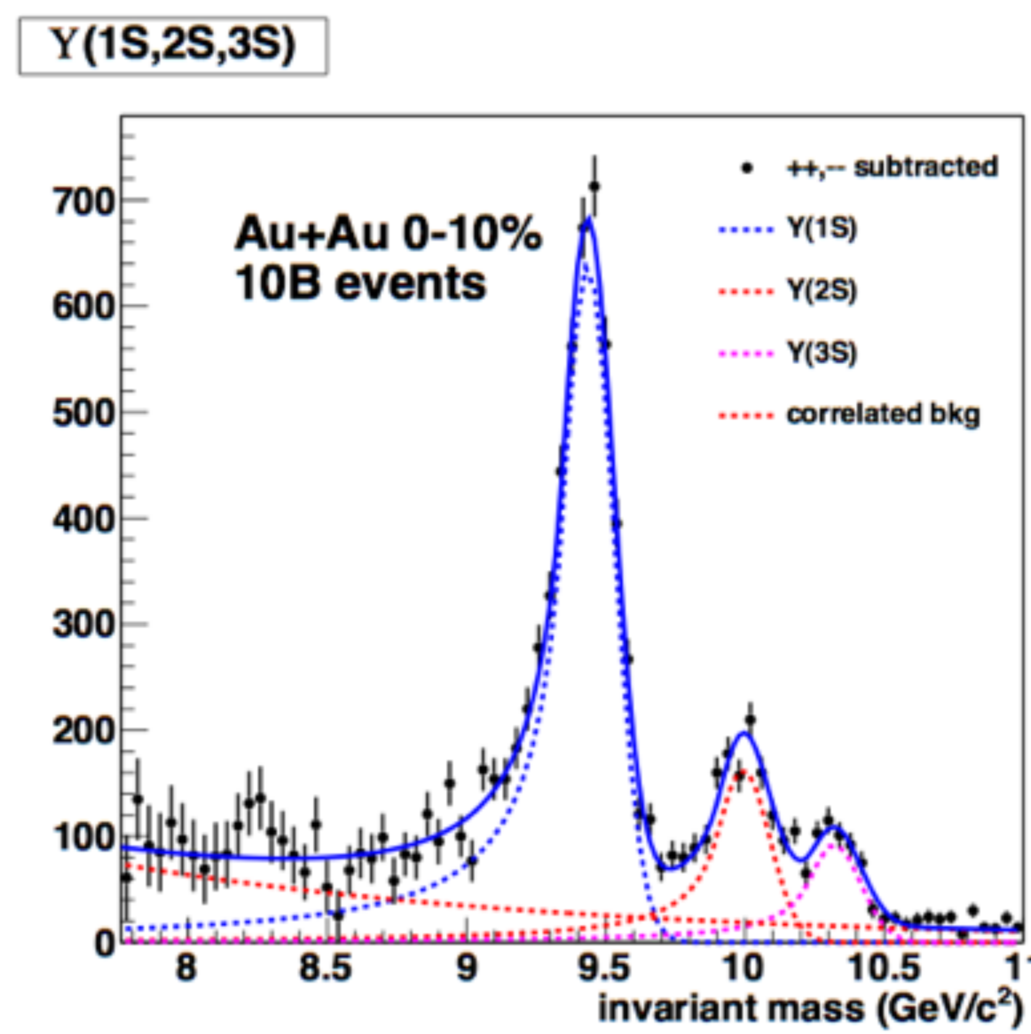
- 26 μm for p_T = 1-2 GeV/c

Results to date - silicon tracker - AuAu central

Fast simulation of background under Upsilons for 0-10% centrality AuAu collisions

- Assumes hadron rejection of 90 (→70% efficiency for single electrons)
- Based on measured pion cross sections in AuAu collisions





Moving forward

Up to the pCDR, simulations work has been done using an essentially ideal (i.e. perfect) detector.

The detector model in GEANT 4 uses cylinder cell geometry
It is assumed that all cells are alive, and are read out individually

Now we need to start on the hard work of making it realistic.

For each of the tracking options, there are conditions imposed by real life that we need to consider before we can conclude that a detector configuration can do our physics.

I will consider each tracking option in turn, and discuss these.

Moving forward - reusing the PHENIX pixels

The PHENIX pixels have significant dead areas due to bump-bonding failures. We need to understand what the "cost" to the physics programs would be.

1) If we insist on 7 layers being hit, the dead areas in the pixels would leave us with a significantly reduced track efficiency - perhaps too small for Upsilons (need 2 tracks) and B-tagged jets (need 3 tracks).

2) If we do **not** insist on 7 layers being hit (i.e. require one pixel layer)

- We cannot measure track DCA, so not useful for B tagged jets.
- The pattern recognition suffers quite a bit - can still do jet fragmentation functions?

Can high p_T fake tracks be rejected using a match to the calorimeters? Probably not an issue for the Upsilons (peak in the mass spectrum).

Use different tracking requirements for different physics programs?

Moving forward - the silicon tracker

1) We can not read out all of the strips:

Inner layer (S0a, S0b):	all strips are read out individually
Intermediate layer (S1a, S1b):	3 strips are ganged together
Outer layer (S2):	6 strips are ganged together

2) No detector is 100% efficient:

If we require hits in all layers of a 7 layer tracker, and the efficiency of each layer is ε, the track efficiency is ε^7. If the layers are 98% efficient:

the single track efficiency is 87%

the pair track efficiency is 75%

Study configurations and strategies to optimize track efficiency while preserving performance.

3) Our simulations so far have assumed 7 tracking layers. If we need better pattern recognition (likely), we may need stereo layers (for example). But stereo layers trade track resolution for pattern ID.

- How to improve pattern recognition with minimal impact on cost?

Moving forward - the TPC

Three issues need to be addressed

1) Effects of space charge at very high rates:
   - This is a specialized simulation being carried out by the SUNY SB group.
     - First results expected in weeks.

2) More realistic simulation of gas transport (more of a detail).

3) Track matching to the pixels
   - Do we need an intermediate silicon layer?

Moving forward - A MAPS pixel detector

A three layer MAPS pixel detector (similar to the ALICE ITS upgraded inner barrel) would have several advantages over the reused pixels.

- Better pattern recognition (adds one more layer)
- Better DCA resolution
- Better track efficiency (assuming high live fraction)

This would have a huge impact on the B-tagged jets performance.

We need to study how the combination of a three layer MAPS pixel detector performs in combination with the silicon strip tracker and the TPC

- emphasis on B-tagged jets

Systematic improvements

An effort is underway (led - and so far mostly staffed - by Mike McCumber) to overhaul the tracking code and macros.

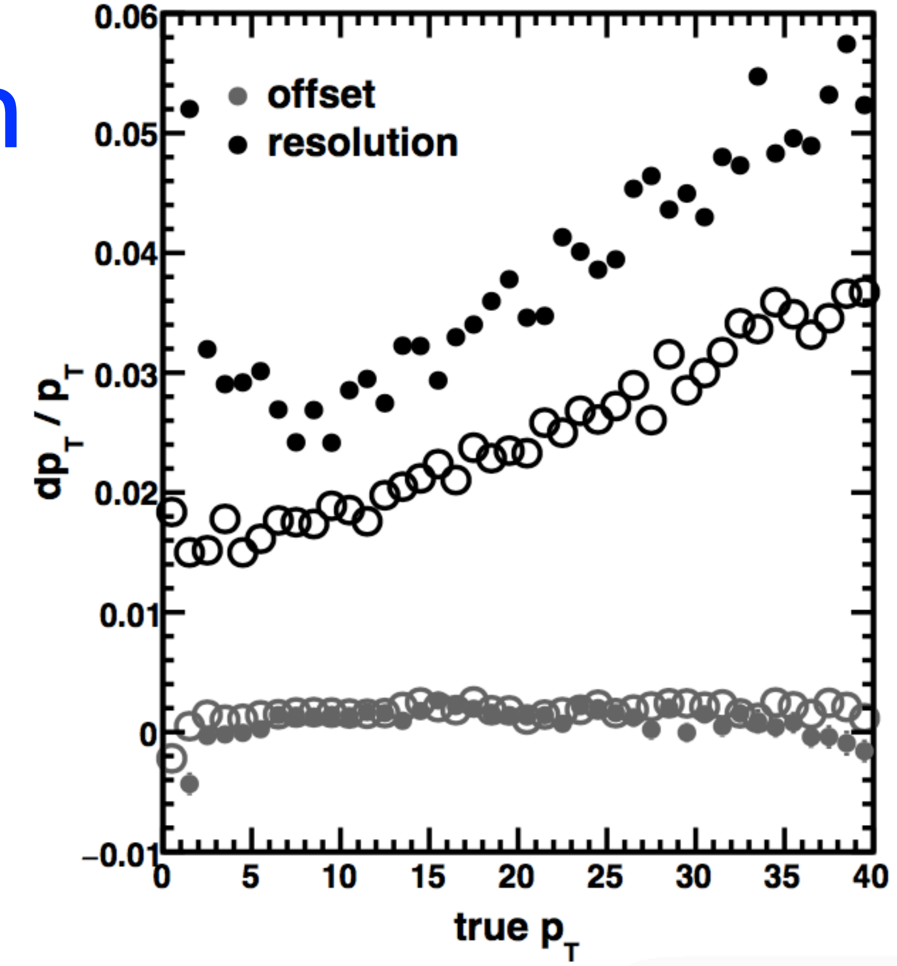
Code:

- Reorganized truth information to allow sensible evaluation
- Also pass truth info forward during processing
- -50% CPU for HIJING events with evaluation
- Currently: Adding purity vs efficiency analysis tool

Macros:

- Have a standard macro for each of the four tracking detectors
- Currently cylinder based (real ladder geos later as software develops)
- Realistic estimates of dead area (92.5,72.5,98x5)%
- Pixel P0/P1=13/19 ladder config move radii to 2.48/3.63 cm
- Maps has 3 inner layers (8 layer tracker, software config for 8-hits)
- Strip layers have S1ab and S2 channel ganging and pCDR geometry
- Ported TPC example - fixed inner cage location, added outer cage
- Decrease B from 1.5T to 1.4T

First look for silicon



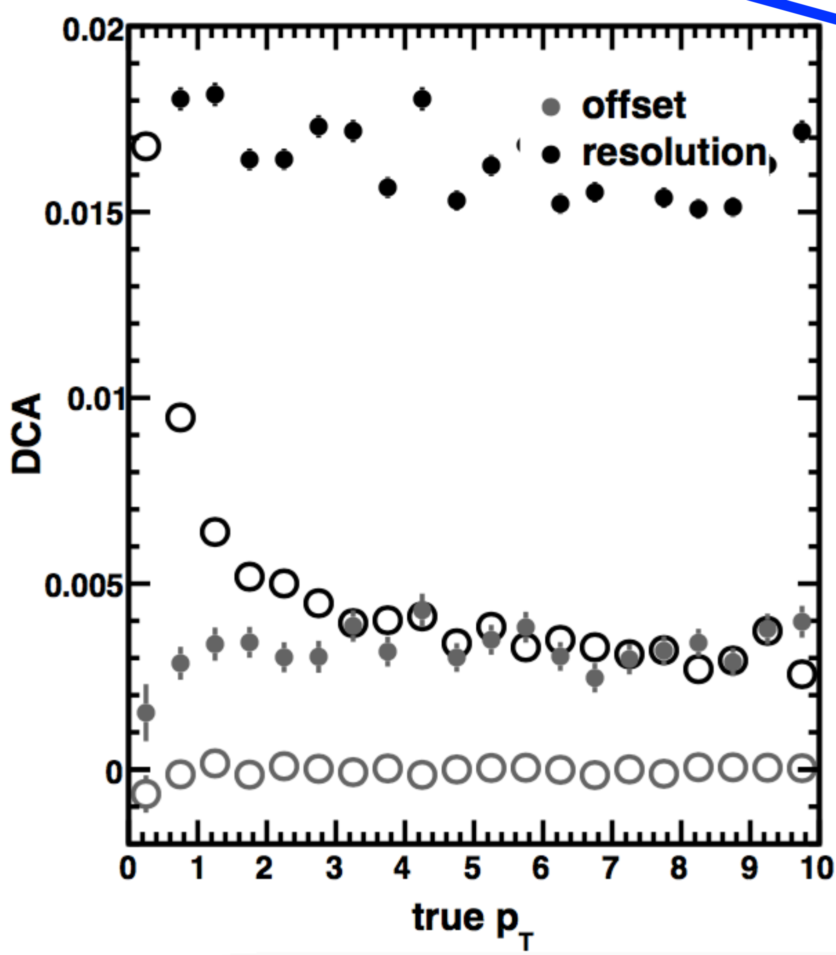
Inner silicon:

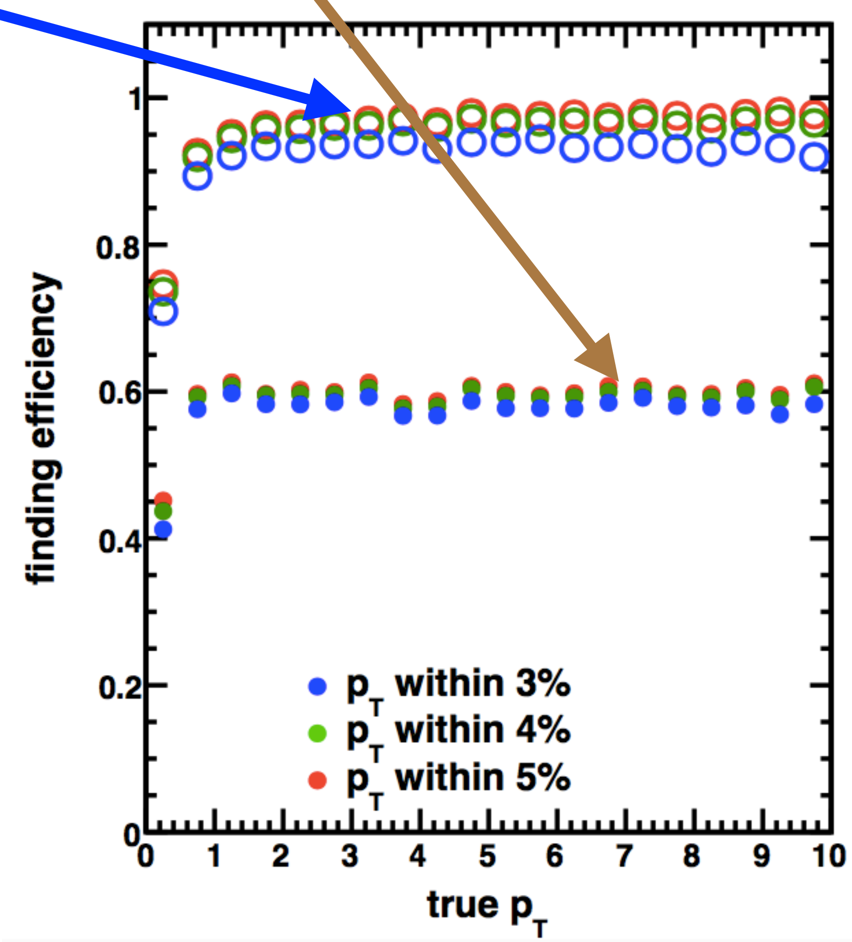
- Layer 1 — 72% efficient
- Layer 2 — 92% efficient

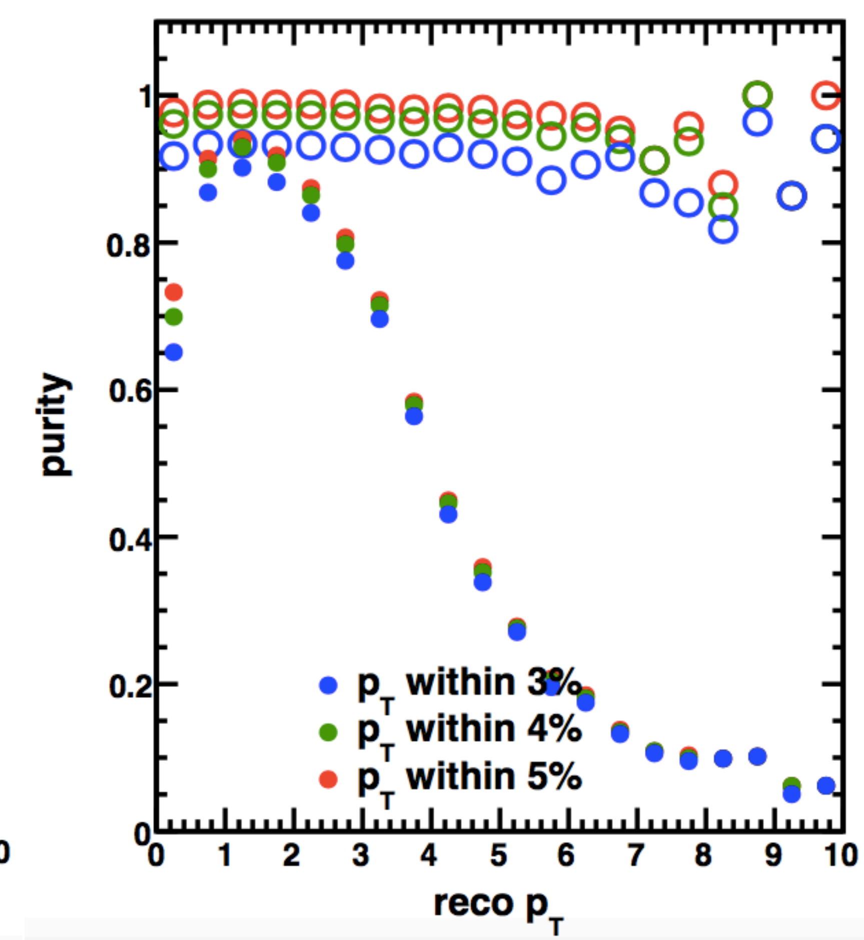
Outer Silicon:

- Layers 3-4: read out all strips individually
- Layers 5-6: gang 3 strips per readout channel
- Layer 7: gang 6 strips per readout channel

Open = perfect detector, solid = dead + ganged







Tracking performance criteria

We have recently decided to adopt a set of criteria for tracking performance that can be applied to all combinations of our 4 tracking detector options - in progress

Physics Channel	Physics requirements	Momentum resolution	DCA resolution	eID h rejection	Single track off.	Fake track rate
Y-> ee	ΔM = 100 MeV Aε = 50% of geom. acceptance	ΔpT < 1.2% (1-8 GeV/c)	N/A	> 90	90% (>2 GeV/c) ?	x% (before CEMC) y% (after CEMC)
D'(z)/D(z)	σ^{h}/σ^{jet}= x% z = 0-0.8	ΔpT < 4% (1-40 GeV/c)	N/A	N/A ?	x% high pT y% low pT	x% within jet y% overall
b-jet ID via track counting	35% purity at 45% efficiency	?	< 70 μm	N/A	x% (set by 35% @ 45% goal)	y% (set by 35% @ 45% goal)
b-jet ID via secondary vertex	35% purity at 45% efficiency	?	< 70 μm/(2-3?)	N/A	90% (>2 GeV/c) ?	y% overall
γ+h jet + h	h p_T below jet reco threshold	?	N/A	N/A	90% (>2 GeV/c) ?	y% overall pT dependent
Particle flow jets	?	?	N/A	N/A	90% (>2 GeV/c) ?	y% overall pT dependent

Longer term

1) Make realistic ladders in G4 for silicon (strips, reused pixels, MAPS)
- A model was made for the revised MIE strip design (SVX4 chip)
- Waiting for configuration to fully stabilize for FPHX strip version
- Maybe import model of ALICE ITS inner pixels for MAPS?

However - while we are still optimizing the configuration - using the cylinder cell model makes the most sense.

2) Add matching to the calorimeters. This is a much more demanding simulation, but we need to understand the effect of calorimeter matching on fake rates.

3) We need to simulate tracking performance inside a jet cone (where there is a relatively large number of higher momentum tracks).
- Can we adequately measure jet substructure?